Journal of Natural Gas Science and Engineering 2 (2010) 153–162

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

journal homepage: www.elsevier.com/locate/jngse

Using operations research to optimise operation of the Norwegian natural gas system

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A R T I C L E I N F O

Article history:
Received 18 February 2010
Received in revised form
12 May 2010
Accepted 12 May 2010
Available online 11 June 2010

Keywords:
Natural gas
Network transportation
Energy
Mixed-integer programming
Optimisation
Decision support system

A B S T R A C T

Decisions regarding natural gas production, processing and transportation depend on each other, and knowledge about how partial changes in a gas transmission network influence the network capacity and flexibility is crucial in ensuring efficient system operation. SINTEF has developed a decision support tool, GassOpt, which is based on mixed-integer optimisation. The model objective is to maximise the flow throughput or profit for a given technical state of a natural gas network. The objective of this work has been to develop extensions to the GassOpt model mainly related to modelling of gas processing and energy consumption related to compression, and to analyse their impact on network operation. The extended GassOpt model represents and analyses a gas transport network in more detail, in particular in discovering bottlenecks, related to gas quality, contaminants and energy efficiency, which have obtained increased focus in recent time. GassOpt is a general tool for gas network optimisation, but applied on the Norwegian gas transport network specifically. The GassOpt tool is used to evaluate the current network as well as possible network extensions. Our approach ensures optimal operation of the network by considering the complete system and provides valuable insights in the dependencies between the different parts of the system. Tests show that the model represents actual network operation in a very good way.

1. Introduction

1.1. Problem statement

Decisions regarding natural gas production, processing and transportation depend on each other, and knowledge about how partial changes in a gas transmission network influence the network capacity and flexibility is of major importance for system operation. A decision support tool, GassOpt, is previously developed by SINTEF (Tomasgard et al., 2007; Rømo et al., 2009) to optimise the network configuration and routing of gas for the main Norwegian shipper of natural gas, Statoil, and the independent network operator, Gassco. The basic theory and principles are outlined in Tomasgard et al. (2007). The objective of this optimisation tool is to maximise the flow throughput or profit for a given technical state of the Norwegian natural gas system. Recently, there has been increased focus on the importance of gas quality impacts on network capacity. Restrictions regarding gas quality are acknowledged as a major challenge when introducing new fields with larger variations in quality and higher CO_2 content into the existing network. Also, greater attention is being paid to energy efficiency and environmental emissions in gas export. Operating efficiency is the major way to reduce emissions and energy use, in addition to its impact on system operating costs. All these aspects require refinement of the gas quality and energy consumption modelling in GassOpt. In this way, the analyst will get a significantly better tool for evaluating throughput potential by adding more complex bottlenecks in the network. In general there is also achieved an increased value by representing a more precise physical representation of the system. The model results then communicate better with a wide range of engineering specialists working with these systems.

The objective of the work presented here has been to develop extensions to the GassOpt model, mainly related to modelling of gas processing and compression, and analyse their impacts on system optimisation and operation. Our approach ensures technically and economically optimal operation of the network by considering the complete system and provides valuable insights in the dependencies between the different parts of the system. The recent extensions in GassOpt will make solutions on system operation richer. This paper will describe these model extensions and their impacts on system optimisation.

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doi:10.1016/j.jngse.2010.05.004

Nomenclature

Symbols

a, b, C, c, n, u, y, x	constants
const	constant representing physical properties of a pipeline
D	pipeline diameter [m]
E	pipeline efficiency factor [−]
F	the number of input, output pressure pairs in pipeline flow linearisation
f	one input, output pressure pair number, $f = 1,\ldots,F$
G	gas specific gravity [−]
GCV	gross calorific value [MJ/scm]
L	pipeline length [m]
MW	molecular weight of gas composition [kg/kmol]
P	power [MW]
PI	fixed inlet pipeline pressure [bar]
PO	fixed outlet pipeline pressure [bar]
p	pressure [bar]
$\overline{p}$	specified normal operating pressure [bar]
Q	flow rate [Mscm/d]
$\overline{Q}$	specified normal operating flow rate [Mscm/d]
T	temperature [K]
Z	compressibility [−]
WI	Wobbe index [MJ/scm]
η	compressor efficiency
κ	specific heat ratio [−]

Subscripts

1	pipeline inlet
2	pipeline outlet
air	air, reference
d	compressor discharge
i	compressor inlet
std	standard conditions

Abbreviations

CO_2	carbon dioxide
GCV	Gross calorific value
H_2S	hydrogen sulphide
scm	standard cubic metre
MILP	mixed-integer linear programming
NCS	Norwegian continental shelf
WI	Wobbe Index

1.2. Background

The gas transport system on the Norwegian continental shelf (NCS) consists of 7800 km of subsea pipelines and is the largest offshore network of its kind in the world (see Fig. 1). In addition to pipelines, the gas transport system includes offshore platforms and land-based processing terminals, which process and compress natural gas. Dry gas is exported from these terminals through pipelines to exit terminals in the UK and continental Europe, where the gas is delivered for sale. Meeting these sales gas commitments is important. Failure to do so would result in gas sale losses, as well as reducing deliverability[1] and hurting the reputation of gas shippers.[2] Gas flowing through the Norwegian network represents approximately 16% of European gas consumption, and the system has a capacity of 120 billion scm[3] a year. Dry gas exports from the NCS totalled 96.1 billion scm in 2008 (Nordvik et al., 2009). That makes Norway the second largest net gas exporter on world basis (IEA, 2009).

The Norwegian gas transport system with its interconnected pipelines and processing terminals is large and complex. Variation in gas quality adds complexity to the problem. This makes it challenging to operate the system at maximum capacity. System effects are prevalent, and the network must be analysed as a whole to achieve optimal operation (Midthun et al., 2007). That requires detailed knowledge of network integration, operational flexibility, the relationship between customer nominations, pipeline flow and pressure, gas processing, compressor station operation, and the effects on optimal operation and energy efficiency. Therefore, it is important and necessary with clear procedures and models showing how to operate the system to optimality, securing flexibility, capability and availability of the gas export system.

The GassOpt tool allows the users to graphically model their network with nodes and arcs in a graphical modelling environment, and to easily run optimisations for finding the best solutions quickly. Graphical network presentation is also used to give the users easier access and understanding of the results of the network optimisation. Fig. 2 shows the graphical modelling of the Norwegian natural gas network. Squared nodes in the illustration contain subsystem with further nodes and pipelines. The figure also illustrates the network complexity. Statoil and Gassco use the model to analyse the gas network, and to identify and reduce capacity and quality bottlenecks. It also has a major role in assessment of possible network extensions. Gassco uses the model to estimate future capacity of the network as input to the capacity booking process for the gas shippers. Statoil estimates the accumulated savings related to their use of GassOpt to be in the order of NOK 10 billion (USD 1800 billion) (Rømo et al., 2009).

2. Methodology and the GassOpt tool

GassOpt is based on mixed-integer linear programming (MILP) from the fields of Operations Research (OR), and the model objective is to maximise the flow throughput (or profit) for a given technical state of the network. The model is a single period planning tool used for short, medium, and long term planning. A detailed formulation and description of the model can be found in Tomasgard et al. (2007), and Rømo et al. (2009). XpressMP, a general MILP solver, is chosen as the platform in the development of GassOpt.

GassOpt is designed for analysis of transportation possibilities. Primarily, it is used for optimal routing and mixing decisions from a flow maximisation perspective. Secondly, it can be used to reroute natural gas when unexpected incidents in production units or pipeline lead to reduced capacity. It can also be applied by shippers for capacity planning and booking purposes. The network model include flow balances, blending of different gas qualities from different fields, processing nodes for extracting components of the natural gas, compressor nodes, node pressure and the non-linear nature of pressure drop in pipelines. The model describes a steady state situation where the network is in equilibrium in terms of

[1] Deliverability is a measure of nomination fulfilment. It is calculated by dividing actual gas delivered by the nominated volume for the year in question.

[2] A shipper is the owner of gas tendered for shipment in the transport system, who has made a booking of transport capacity and will transport gas in the system.

[3] Standard cubic metre, defined as the volume under standard conditions, i.e. a temperature of 15 °C and a pressure of 1.01325 bar.